CHAPTER 4

CONCRETE PAVEMENTS

4-1. Methods of procedures

This section described methods and procedures for maintenance, repair, and resurfacing of concrete pavements. Since surface failure must be corrected at the source, probable causes are discussed and repair measures are described. The principles outlined apply to reinforced and nonreinforced pavements for roads, airfields, parking areas, openstorage areas, and walks.

a. Normal maintenance and repair. Normal maintenance on concrete pavements consists principally of the care of joints, sealing of cracks, replacement of random broken slabs or similar sections, and the correction of minor settlement and drainage faults. Repair consists of the work required to restore a distressed pavement so that it may be used at its original designed capacity and/or accommodate the current mission.

b. Description and composition. Concrete is a material manufactured from portland cement, water, fine aggregate (sand), and coarse aggregate (gravel or crushed rock), with or without additives (air entraining, fly ash), developed to achieve the strength and durability of natural stone. Concrete generally achieves its initial set less than 1 hour after water is added and will become fairly hard within 6 hours. Concrete will continue to gain strength at an ever decreasing rate for many years as long as moisture is retained within the consolidated mass, and there is not adverse chemical reaction either internally or due to external action. For example, during the first days, the concrete will normally attain about 80 percent of its 28-day strength and about 75 percent of its 90-day strength if adequately cured. The concrete strength at 28-day is normally used in pavement design for roads and 90-day is normally used for airfields. If high-early-strength cement is used, less time is required for the concrete to develop design strength. If hydraulic cement which contains pozzolans is used as a replacement, the rate of strength gain, especially at the early ages, will be lower.

4-2. Properties and behavior

Concrete pavement has a relatively long economic life when properly designed, constructed, and well maintained. In general, the economic life of pavement ends when (under the effects of traffic, weather, and lack of proper maintenance) it has broken into small unstable sections. Subsequently, unsatisfactory surface problems develop and costly, extensive maintenance is required. Durability is improved by keeping the surface smooth, especially at joints and cracks.

Maintaining the joints to minimize the infiltration of water and to prevent the entrance of incompressible foreign material is essential for long life. Frequent loadings greater than those for which the pavements were designed will cause early failure of the pavement.

a. Rigidity. Portland cement concrete is classified as a rigid pavement. Because of its beam action or resistance to bending, it can bridge small, soft, or settled areas of a subgrade. Overloading of concrete pavements can result from the applied loads being greater than the design load or the foundation support being reduced as a result of pumping, excessive moisture, etc. Once cracking has commenced, continued loading will cause additional cracks or breaks until complete failure of the pavement results (fig 4-1).

b. Strength. The design of concrete for use in pavements is based on limiting the tensile stresses produced within the concrete by applied loads. Flexural strength, which is a bending resistance property, is used in the design of a rigid pavement. Compressive stresses exist in concrete pavement slabs but in relation to the compressive strength are insignificant. The compressive strength is about 8 to 10 times the tensile strength. The relative strength as well as the durability is directly affected by the quality of the cement, purity of the water, and cleanliness, durability, and gradation of the aggregates. Other important factors include the water to cement ratio, density, amount and type of admixtures, proportioning and mixing of materials, and placement and curing methods.

(1) *Cement.* The characteristics of portland cement manufactured in the United States are reasonably standardized and meet rather stringent specifications regarding composition. Cement manufactured in foreign countries must be investigated carefully to determine physical and chemical properties before approval is given for use in the construction of U.S. military installations. The quality and composition of foreign manufactured cement may vary and may not meet U.S. Government specifications as few foreign countries have as close control of cement manufacture as the United States. The standard types of portland cement are discussed in the following paragraphs.

(a) *Type I-normal.* This type is used for general construction when not subject to sulfate attack and where hydration heat will not cause an objectionable rise in temperature.
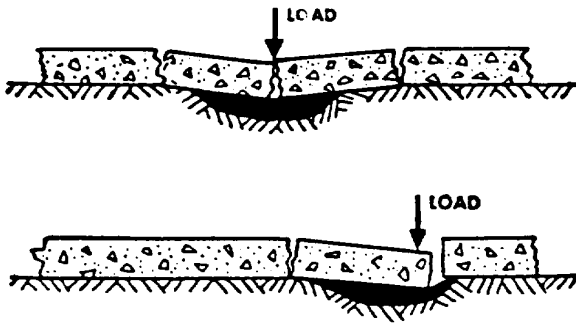
Figure 4-1. Pavement failures.

(b) *Type II-modified.* This cement has a lower heat of hydration than the normal Type I and generates heat at a slower rate. It is also a moderate sulfate-resisting cement. Modified cement is used when concrete is placed in warm weather or in locations where a high temperature rise is objectionable.

(c) *Type III-high-early-strength.* This type of cement is used where a high strength is needed very quickly. This may be due to a demand for early use or in cold weather construction to reduce the period of protection against low or freezing temperatures.

(d) *Type IV-low heat.* This cement is used when the amount and rate of heat generated must be kept to a minimum. Type IV cement develops strength at a slower rate than Type I cement, but prevents the development of high temperatures which can cause contraction cracking upon later cooling. Type IV is generally used for massive structures such as large gravity dams wherein temperature rise from the heat of hydration is critical. This type of cement will seldom, if ever, be used in maintaining and repairing pavements.

(e) *Type V-sulfate resistant.* Sulfates may be present in the water used to mix the concrete or may be created by sulfurous gases from nearby industrial areas and will react chemically with the cement compounds. Sulfate attack, however, occurs in foundations or other concrete in contact with the earth in certain regions, and it is caused by a reaction of the ground water containing dissolved reaction minerals or acid with the hardened cement. Type V cement is highly resistant to sulfate attacks. This cement is usually available only on special order.

(f) *Low-alkali cement.* When laboratory investigations or past-performance records demonstrate that the concrete aggregate (approved for a project) is potentially reactive with alkalies in the cement, the cement (regardless of type) should also be required to meet the requirements for low-alkali cement.

The combined sodium oxide and equivalent potassium oxide content shall not exceed 0.60 percent.

(2) *Water.* Water used in mixing should be clean and free from deleterious amounts of acids, alkalies, or organic materials. Generally, water ordinarily used for domestic and industrial purposes is suitable for use in mixing concrete. Seawater may be used if the salt content is not excessive. The detrimental effect on concrete caused by the use of seawater is usually small, except in very lean mixtures. But in reinforced concrete construction, the corrosion of the steel can be serious. A loss of 10 to 20 percent in compressive strength can be expected when using the same amount of seawater as fresh water. This can be moderately compensated by reducing the water-cement ratio. The maximum concentration of salt by weight allowed in the mixing water is about 1 percent of the weight of the cement.

(3) *Aggregates.* To ensure a dense composite mixture, the aggregate should be well graded from coarse to fine. Aggregates should be hard and sound to resist abrasion and weathering. They should not contain substances which react unfavorably with the chemical components of the cement used in the concrete mix. The maximum size of coarse aggregate used in pavement concrete should not exceed one-fourth of the pavement thickness. In no case should the coarse aggregate exceed 2-inch nominal size.

(4) *Admixtures.* An admixture for concrete is any material other than water, aggregate, or cement that is intentionally used as an ingredient in a concrete mixture and is added to the concrete batch either immediately before or during the mixing of the concrete. Admixture is used to make the concrete to which it is added more suitable or less expensive. An admixture will be used only when advantages cannot be more easily or more economically obtained in any other way. There are a number of categories of admixture:

- air entraining,
- retarding,
- water-reducing,
- air detraining,
- gas forming,
- expansion producing,
- finely divided minerals,
- damp proofing and permeability reducing,
- bond and chemical admixtures which reduce alkali-aggregate expansion,
- corrosion and inhibiting,
- fungicidal,
- germicidal,
- insecticidal,
- flocculating,
- coloring.

Only three of these admixtures mentioned will be discussed in this manual. A complete discussion of all admixtures is contained in the American Concrete Institute Guide for the Use of Admixtures in Concrete.

(a) *Air-entraining admixtures*. An airentraining admixture generally has the properties of a soap or a detergent in that, when mixed with water, it will make foam. Adding an air-entraining agent in concrete will improve workability, reduce bleeding, and, most importantly, cause the concrete or mortar to be resistant to damage by freezing and thawing. The use of air entrainment permits the production of concrete that will not be damaged by freezing and thawing even though it is repeatedly frozen in a water-soaked condition. Concrete used for pavement should generally be air entrained containing between 4 and 7 percent by volume of air. Possible exceptions would include areas where aggregate strength is marginal and freeze-thaw is a negligible issue. When the proper amount of entrained air is added, the workability of the concrete will be greatly increased allowing the water content to be reduced which will increase the strength.

(b) Accelerating admixtures. Some accelerators used as admixtures change the time of setting without increasing early strength while others increase early strengths without changing the time setting. The most widely used accelerator is calcium chloride; this material can be safely used in amounts up to 2 percent by weight of the cement. Calcium chloride should never be used in prestressed concrete, in concrete in which there are embedded items such as aluminum electrical conduit, or in concrete that is placed on or in permanent metal forms, especially galvanized metal. Calcium chloride or any other accelerator should normally be used only in case of emergency, such as to accelerate set to prevent damage due to freezing or to open repaired areas to traffic within the shortest possible period of time. Caution should be exercised when using accelerators, such as calcium chloride, in hot weather as the time of setting will be substantially decreased.

(c) Retarding admixtures. Most retarding admixtures have a water-reducing effect which affects the setting time of the concrete. At normal temperatures and in normally used amounts, the setting time of concrete can be extended by one-third to one-half the normal time and greater delays obtained by using larger amounts of retarding admixtures. As with accelerators, retarders are normally used only in emergencies such as to prevent premature set on hot, dry, windy days.

(5) *Proportions.* The water-cement ratio theory should be observed when proportioning the amounts of water and cement in the mixture. A minimum of approximately 2½ gallons of water is required to hydrate (the chemical action which causes the concrete to harden) 94 pounds of cement. But more water must be added to compensate for evaporation and losses resulting from absorption by the aggregate in the concrete mixture, base, or subgrade and to provide fluidity which improves workability. Approximately 6 gallons of water per 94 pounds of cement represent the approximate maximum water-cement ratio which will produce a durable, frost-resistant concrete. Therefore, 4 to 5 gallons per 94 pounds of cement is generally considered adequate. Strength decreases proportionately as more water is added (fig 4-2). A high water content is not economical since the weakening effects on durability, compressive, tensile, flexural, and bond strengths, and weathering offset any apparent advantages of workability. The most practical method of proportioning available to the installation engineer, the book method, will normally be used if standard mixes are not available.

(6) *Book method of mix proportioning.* The selection of the quantities of cement, water, fine and coarse aggregates, and air-entraining admixture required to produce concrete of desired characteristics may be made from tables established for the purpose. The tables have been set up for aggregates having properties within the limits specified and will produce satisfactory quality concrete for such aggregates. The determined mix proportions are not always the most economical. Hence, the trial batch method will be used to design the mix when time is
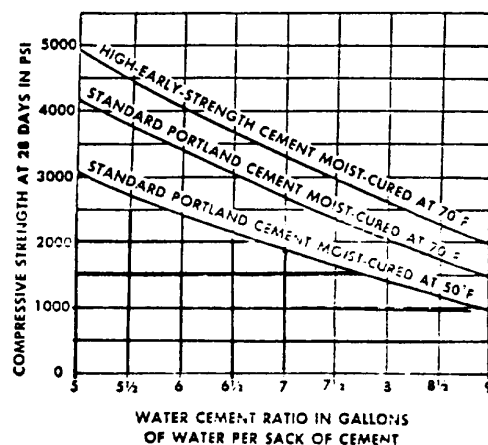

Figure 4-2. Age-strength relationship.

available and the size of the job warrants the laboratory effort required. The mix proportions given by the book method may be modified if the desired workability is not obtained. Such modification, as needed, will be made by changing the proportions of fine and coarse aggregate. The watercement ratio should not be changed in making these modifications. The quantity of cement is established by the water requirement shown in table 4-1. Under field conditions where inspection and careful control of concrete quality are difficult, the cement content should exceed an established minimum. Recommended slumps (in inches) for various types of construction are given in table 4-2. The stiffness of the mix is inversely proportional to slump. In the absence of any criteria, concrete will be placed as stiff as possible while maintaining a homogeneous mass. The fineness modulus of the sand is determined by sieving or estimating. Tables 4-3 and 4-4 give mixes for air-entrained and nonairentrained concrete.

Using the water-cement ratio and aggregate size required, weights of water and cement should be selected per cubic yard of concrete.

(7) *Mixing and placing.* Thorough mixing is necessary to completely coat the aggregate with cement paste and to ensure the uniform distribution of all components. Care should be taken during transportation and placement of concrete to avoid segregation of the ingredients. Spading and vibrating are performed during concrete placement operations to ensure maximum density. These operations must be complete before the concrete takes its initial set. Good practice prohibits retempering of a concrete batch. A 1-minute minimum for actual mixing time is prescribed after all ingredients are in the mixer, and a maximum time is placed for completion of all mixing and placement operations.

Table 4-1. Approximate mixing water requirements for different slumps and maximum sizes of aggregates*

| Slump, in. | Water, gal/yd^3 of Concrete, for Indicated Maximum Sizes of Aggregate, in. | | | |
	½	¾	1	1-½
Nonair-Entrained Concrete				
1 to 2	40	37	36	33
3 to 4	44	41	39	36
5 to 6	46	43	41	38
Approximate amount of entrapped air in nonair-entrained concrete, percent	2.5	2	1.5	1
Air-Entrained Concrete				
1 to 2	36	33	31	29
3 to 4	39	36	34	32
5 to 6	41	38	36	34
Recommended average Total air content,** percent	7	6	5	4.5

* Mixing requirements are for reasonably well-shaped aggregates.
** Air content will be designed for each project, based on materials to be used and experience.

Table 4-2. Recommended slumps for various types of construction

Types of Construction	Slump, in.*	
	Maximum	Minimum
Roads, streets, airfield pavements	2	1-1/4**
Bridge decks	2-3/4	2**
Sidewalks, driveways, and slabs on ground	4	2**

* Based on use with high frequency vibrators. In no case will the slump exceed 4 inches.
** When a slipform paver is used, the slump will be between ½ and 1-½ inches.

(8) *Temperature.* If concrete is exposed to elevated temperature, high wind velocity, and low relative humidity shortly after finishing, some of the mixing water will be lost to evaporation, and the surface will shrink, forming cracks in pavement. High temperatures will accelerate the hydration process resulting in more rapid strength gain as shown in figure 4-2 by the relative positions of the curves for curing at 70 and 50 degrees F. Concrete will be protected against freezing after placement for at least 14 days. If the concrete freezes, the hydration process stops, and there will be little or no strength gain.

(9) *Aging concrete.* Increase of strength with age is shown in figure 4-3.   High-early strength is attained by the use of normal proportions of highearly-strength cement, the use of additional standard portland cement (25 percent), or the addition to the mix of not more than 2 percent (by weight of cement) of calcium chloride.

4-3.   Causes of concrete pavement distress

Detailed distress identification criteria can be found in AFR 93-5 for airfields and TM 5-623 for vehicular pavements.   Table 4-5 lists pavement distresses and suggested maintenance and/or repair procedures.

a. *Expansion and contraction.* Various methods for expanding and contracting concrete are listed below.

(1) *Temperature effects.* Concrete expands when temperatures increase and contracts when temperatures decrease.   Pavement slab tends to lengthen in hot weather and shrink in cold weather.

(2) *Moisture effects.* Concrete expands as it absorbs moisture and contracts with loss or evaporation of the moisture. This may affect temperature stresses, depending on conditions. If rainfall is followed by hot weather, the effects combine and slab expansion may result in blowups. However, if a temperature drop immediately follows the precipitation, slab expansion and contraction may counteract each other, and no dimension changes will be noticeable.

Dense concrete resists water absorption.   In cold climates, concrete containing an excess of entrapped air, if filled with water, may disintegrate as a result of freezing and thawing. The use of airentraining agents minimizes this. Maximum combined temperature and moisture stresses do not normally exceed the resistant limits of good quality concrete pavement, especially if joints are maintained free of noncompressible material to provide for free slab movement.

(3) *Joint movement.* Transverse and longitudinal joints are constructed in the concrete pavements to relieve stresses caused by volume changes and to prevent development of undesirable and unsightly cracks.

(a) *Expansion joints.* Expansion joints are installed primarily to relieve compression stresses caused by expansion of the pavement. They usually consist of some form of nonextruding filler such as wood, asphalt, impregnated fiberboard, spun glass, or other preformed elastomeric or compressible material which will permit horizontal expansion of the concrete. Expansion joints are used to isolate slabs from other features that move differently such as manholes, buildings, adjacent slabs with different working joint plans, and mismatched joints. Mismatched joints can cause cracks in adjacent slabs.

(b) *Contraction joints.* Contraction joints are installed to relieve tensile stresses due to contraction of the pavement. They are weakened planes usually consisting of grooves sawed or formed or materials inserted in the surface of the concrete. These grooves or separations are intended to reduce the pavement cross section at prescribed locations

Table 4-3. Suggested trial mixes for air-entrained concrete of medium consistency (1- to 2-inch slump)

Water-Cement Ratio lb/lb	Maximum Size of Aggregate in	Air Content Percent	Water lb/yd³ of Concrete	Cement, lb/yd³ of Concrete	Aggregate, Percent of Total Aggregate	With Fine Sand-Fineness Modulus = 2.50			With Coarse Sand-Fineness Modulus = 2.90	
						Fine Aggregate, lb/yd³ of Concrete	Coarse Aggregate, lb/yd³ of Concrete	Fine Aggregate, Percent of Total Aggregate	Fine Aggregate, lb/yd³ of Concrete	Coarse Aggregate, lb/yd³ of Concrete
0.37	1/2	7.5	300	815	41	1060	1520	46	1180	1400
	3/4	6	275	750	35	970	1800	39	1090	1680
	1	6	265	715	32	900	1940	36	1010	1830
	1-1/2	5	245	665	29	870	2110	33	990	1990
0.42	1/2	7.5	300	720	43	1140	1520	47	1260	1400
	3/4	6	280	665	37	1040	1800	41	1160	1680
	1	6	265	635	33	970	1940	37	1080	1830
	1/2	5	245	590	31	930	2110	35	1050	1990
0.47	1/2	7.5	305	650	44	1200	1520	49	1320	1400
	3/4	6	280	600	38	1100	1800	42	1220	1680
	1	6	270	570	34	1020	1940	38	1130	1830
	1-1/2	5	250	530	32	980	2110	36	1100	1990
0.52	1/2	7.5	305	590	45	1250	1520	49	1370	1400
	3/4	6	285	545	39	1140	1800	43	1260	1680
	1	6	270	520	35	1060	1940	39	1170	1830
	1-1/2	5	250	480	33	1030	2110	37	1150	1990
0.56	1/2	7.5	300	540	46	1290	1520	50	1410	1400
	3/4	6	280	500	40	1180	1800	44	1300	1680
	1	6	265	475	36	1100	1940	40	1210	1830
	1-1/2	5	245	440	33	1060	2110	37	1180	1990
0.61	1/2	7.5	305	500	47	1330	1520	51	1450	1400
	3/4	6	280	460	40	1210	1800	44	1330	1680
	1	6	270	440	37	1130	1940	40	1240	1830
	1-1/2	5	250	410	34	1090	2110	38	1210	1990
0.66	1/2	7.5	305	465	47	1360	1520	51	1480	1400
	3/4	6	285	430	41	1240	1800	45	1360	1680
	1	6	265	405	37	1160	1940	41	1270	1830
	1-1/2	5	250	380	34	1110	2110	38	1230	1990

Table 4-4. Suggested trial mixes for nonair-entrained concrete of medium consistency (1- to 2-inch slump)

Water-Cement Ratio lb/lb	Maximum Size of Aggregate in	Air Content Percent	Water lb/yd^3 of Concrete	Cement, lb/yd^3 of Concrete	Aggregate, Percent of Total Aggregate	With Fine Sand-Fineness Modulus = 2.50			With Coarse Sand-Fineness Modulus = 2.90	
						Fine Aggregate, lb/yd^3 of Concrete	Coarse Aggregate, lb/yd^3 of Concrete	Fine Aggregate, Percent of Total Aggregate	Fine Aggregate, lb/yd^3 of Concrete	Coarse Aggregate, lb/yd^3 of Concrete
0.37	1/2	2.5	340	915	42	1100	1520	47	1220	1400
	3/4	2	315	850	35	960	1800	39	1080	1680
	1	1.5	300	815	32	910	1940	36	1020	1830
	1-1/2	1	280	750	29	880	2110	33	1000	1990
0.42	1/2	2.5	340	810	44	1180	1520	48	1300	1400
	3/4	2	315	755	37	1040	1800	41	1160	1680
	1	1.5	300	720	34	990	1940	38	1100	1830
	1-1/2	1	280	665	31	960	2110	35	1080	1990
0.47	1/2	2.5	345	730	45	1250	1520	49	1370	1400
	3/4	2	320	680	38	1100	1800	42	1220	1680
	1	1.5	305	650	35	1050	1940	39	1160	1830
	1-1/2	1	280	600	32	1010	2110	36	1130	1990
0.52	1/2	2.5	345	665	46	1310	1520	51	1430	1400
	3/4	2	320	620	39	1150	1800	43	1270	1680
	1	1.5	305	590	36	1100	1940	40	1210	1830
	1-1/2	1	285	545	33	1060	2110	37	1180	1990
0.56	1/2	2.5	340	610	47	1350	1520	51	1470	1400
	3/4	2	315	565	40	1200	1800	44	1320	1680
	1	1.5	300	540	37	1140	1940	41	1250	1830
	1-1/2	1	280	500	34	1090	2110	38	1210	1990
0.61	1/2	2.5	340	560	48	1390	1520	i2	1510	1400
	3/4	2	320	525	41	1230	1800	45	1350	1680
	1	1.5	305	500	38	1180	1940	41	1290	1830
	1-1/2	1	280	460	35	1130	2110	39	1250	1990
0.66	1/2	2.5	345	520	48	1430	1520	53	1550	1400
	3/4	2	320	485	41	1270	1800	45	1390	1680
	1	1.5	305	465	38	1210	1940	42	1320	1830
	1-1/2	1	285	430	35	1150	2110	39	1270	1990

so that cracks will occur below the weakened plane conforming to a given pattern.

(4) *Warping.* Variations in temperature and moisture conditions between the top and the bottom of concrete pavement cause warping or curling. During the day, surface temperatures may rise a number of degrees while the bottom of the slab, which is protected, remains at a lower temperature. This lengthens the surface dimension while the bottom dimension remains about the same. The slab tends to warp and curl downward at the edges and joints (fig 4-4). At night, the surface drops in temperature much more rapidly than the bottom, and the slab tends to curl upward to the edges.

b. Surface texture. The surface texture of PCC pavements will depend on the type and amount of finishing that was done during construction. In some cases, the type of aggregate used will determine the surface condition. Pavement slipperiness has been a major concern on highways and airfields, and in recent years directional control for vehicles attempting to stop on wet pavement surfaces has been obtained by grooving pavements. Grooving is accomplished by sawing of the hardened concrete. Plastic grooving has been used with some success; however, sawing gives the better surface texture.

c. Construction deficiencies. Deficiencies in the aggregate used will lead to deficiencies in the concrete. The use of aggregates susceptible to polishing should be avoided whenever possible.

The use of polishing aggregate can lead to a loss of skid resistance.

(1) *Unseasonable operations.* Concrete cures and gains strength with time. Extremes in tempera ture, hot or cold, can have a detrimental effect on the short and long-term properties of the concrete (see para 4-1c(8)).

(2) *Improper mixing.* Uncoated aggregate caused by improper mixing will decrease the strength and durability of the concrete. Proper mixing and handling during transportation are important to assure a good concrete mixture (see para 4-1c(7)).

(3) *Poor proportioning.* An improper proportion of any of the ingredients added to the mix can cause distress in the concrete. The degree of distress will depend on the degree of variation from the desired proportion (see para 4-1c(5)).

(4) *Placement errors.* Any placement errors such as over vibrating and segregation will cause pavement distress. These errors can be eliminated by good workmanship and good quality control (see para 4-1c(7)).

d. Water intrusion. Concrete pavements require a base with adequate strength in order to perform well. Any water allowed to infiltrate into the base will damage the base and therefore shorten the concrete pavement useful life. Adequate sealing of
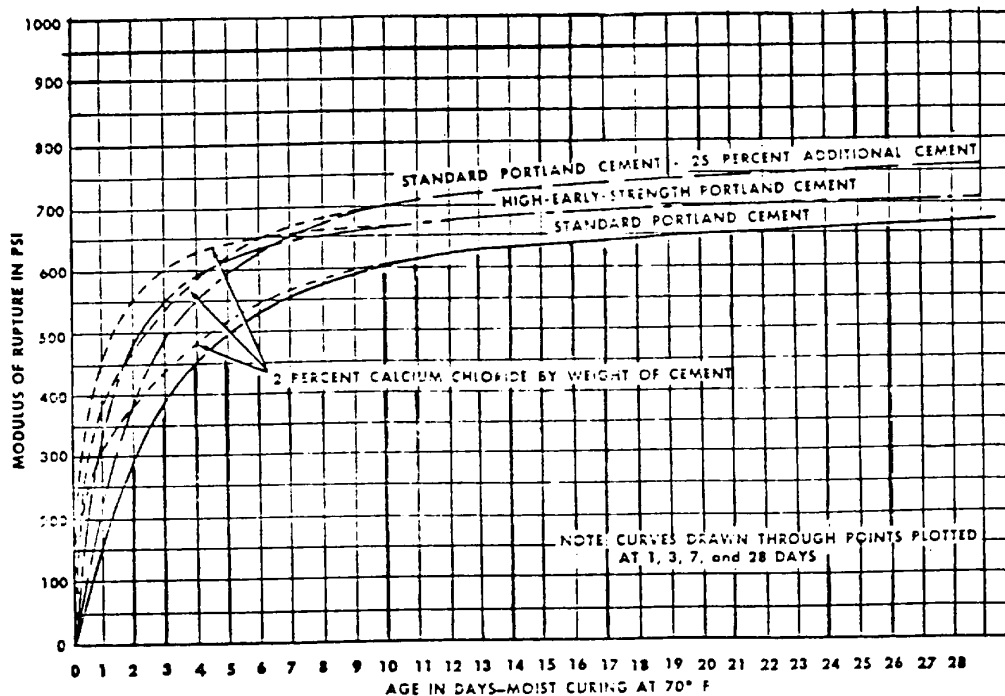

Figure 4-3. Approximate bending strength.

Table 4-5. Pavement distresses and suggested maintenance and/or repair procedures

Distress Type	Do Nothing	Partial Depth Patch (Bonded)	Full Depth Patch	Slab Replacement	Crack Sealing	Joint Sealing	Under Sealing	Slab Jack-Grout	Grinding Slab	Grooving	Notes
21 Blow-ups		L*,M*	H*	H*							*Must provide expansion joint
22 Corner break	L		M,H	H	L,M,H						
23 Divided slab			M,H	L,M							
24 "D" cracking	L	M,H	M,H	H	L*	L*					*If "D" cracks exists, seal all joints and cracks
25 Faulting	L			H				M,H	M,H		
26 Joint seal damage	L					M*,H					*Joint seal local areas
27 Lane/shoulder drop of	L										If predominant, level off shoulder, apply aggregate seal coat
28 Linear cracking	L	H*	H	H	L,M,H						*Allow crack to continue through patch except when using A-C
29 Large patch & utility cuts	L	M*,H*	H*	H	M						*Replace patch
30 Small patching	L	M*,H*	H*		M						*Replace patch
31 Polished aggregate	A										If predominant, apply major or overall repair e.g., overlay grooving
32 Popouts	A										
33 Pumping					A	A	A				
34 Punchouts	L		M,H	H	L,M						
35 Railroad crossing	L										If n or H, level surface
36 Scaling/map cracks/crazing	L	M,H	H								
37 Shrinkage cracks	A										
38 Corner spalling	L	L,M,H									
39 Joint spalling	L	M,H	M,H*			L					*If caused by keyway failure, provide load transfer

Note: L = low severity; M = medium severity; H = high severity; A = has only one severity level.

cracks and joints will prevent water infiltration and subsequent pumping of certain types of soil.

e. *Fuel spills*. Concrete pavements are desirable for use in areas subject to fuel spillage. Concrete pavements are themselves not affected by fuel spills, but in these areas the use of fuel resistant joint and crack sealers is required. Any fuel resistant joint sealer must pass Federal Specifications SS-S-1614B or SS-00200E with the latter required where the sealer would be subject to jet blast.

f. *Chemical intrusion*. Chemical intrusion refers to the concrete's chemical reaction to other materials. The most widespread problem normally encountered is with deicing salts in cold weather regions. The reactions vary with the type of cement and the quality of the aggregate used. Chemical intrusion problems can be reduced by selecting the proper construction materials for the conditions encountered.

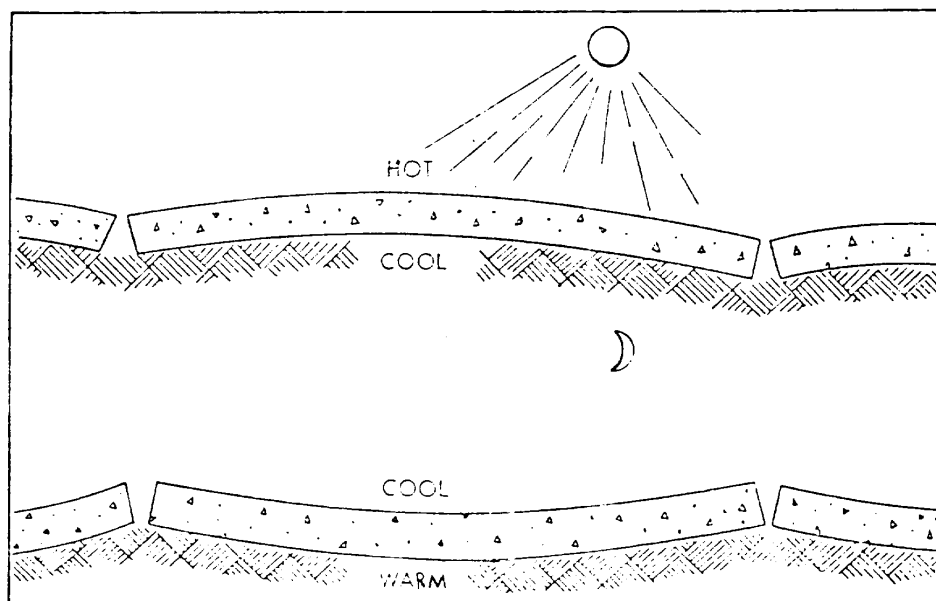g. *Wheel load transfer*. Failure to provide for wheel load transfer across joints (especially during

Figure 4-4. Curling.

repairs and slab requirements). Paragraph 21a(2) gives an explanation of load transfer.

h. Poor joint layout. Poor joint plan layout or violation of a good jointing plan during repairs and slab replacement can cause premature failure. Repairs need to observe the existing plan and provide for proper joint movement (and load transfer). Large slab repairs (all edges) should not be confined without some means of concrete drying construction relief.

4-4. Types of concrete pavement distress
Distresses are of many types. Some pavement distresses are listed below.

a. Blowups. A buckling blowup (fig 4-5) is the localized upward movement of a rigid pavement. The buckling may take the form of a rather serious blowup or may merely shatter the upper portion of the concrete near the joint. This condition is caused primarily by infiltration of incompressible material in joints and possible growth of the concrete. During hot weather, the pressure due to the slab expansion builds up at transverse cracks or joints until buckling or shattering occurs. Buckling or blowups normally occur in thin pavement sections.

b. Corner break. A corner break in a rigid pavement (fig 4-6) is a break which occurs along the edge or corner of a slab. The corner break has the approximate shape of a triangle, the sides of which are formed by a transverse joint or irregular crack and a longitudinal joint or slab edge. Corner breaks are caused by overloading or a loss of uniform subgrade support.

The lack of proper support may be caused by curling or warping in the slab, voids from pumping of the supporting material below the broken or cracked corner, or loss of load transfer at the transverse and longitudinal joints.

c. Divided slab (shattered). A divided slab is divided by cracks into four or more pieces due to overloading and/or inadequate support (fig 4-7). These cracks are usually vertical and extend full depth through the slab.

d. "D" cracking. Another type of cracking, termed D cracking (fig 4-8), is the progressive formation on the surface of a series of fine cracks at rather close intervals, paralleling edges and joints, and curving around corners where joints intersect or cracks intersect edges. It is caused by repetitive freezing and thawing cycles in the presence of aggregates of varying expansiveness and those having an undesirable pore structure. Moisture is critical to the development of D cracking. Thus, if excess moisture can be kept out of the concrete, this type of distress can be retarded.

e. Faulting. When filled areas are not thoroughly and uniformly compacted, differential consolidation or settlement of material underlying the slabs can occur, resulting in faulting of concrete slabs (fig 4-9). This condition may result from loss of fines (through improperly designed subdrains or other drainage systems), pumping under traffic, differential frost heave, and swelling soils.
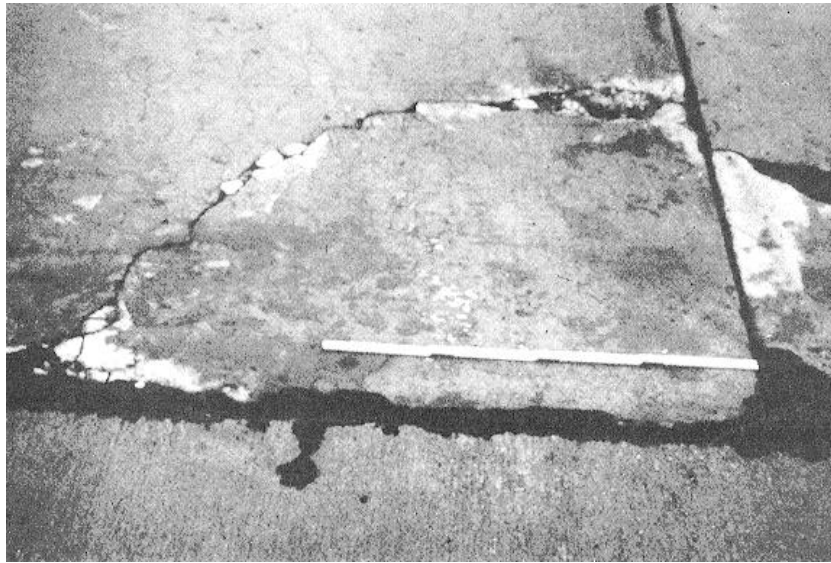
Figure 4-5. Blowup/buckling.

Figure 4-6. Corner break.

f. *Joint seal damage*. Joint seal damage is any condition which enables material to accumulate in the joints or which allows significant water infiltration through the joint (fig 4-10). Accumulation of incompressible materials in the joints prevents the slabs from expanding and may result in buckling, shattering, or spalling. A properly applied pliable joint sealer bonded to the edges of the joint will protect the joint from material accumulation and subsequent water infiltrations. Typical types of joint seal damage are

(1) Stripping of joint sealant.
(2) Extrusion of joint sealant.
(3) Weed growth.
(4) Hardening of the sealer (oxidation).
(5) Loss of bond to the slab edges.
(6) Lack or absence of sealant in the joint.

g. *Lane/shoulder dropoff*. Lane/shoulder dropoff is the differential settlement or erosion between the shoulder and the pavement-lane edge (fig 4-11). It can also be caused by differential heave (frost heave). This drop off can be severe safety hazard for

Figure 4-7. Divided slab.
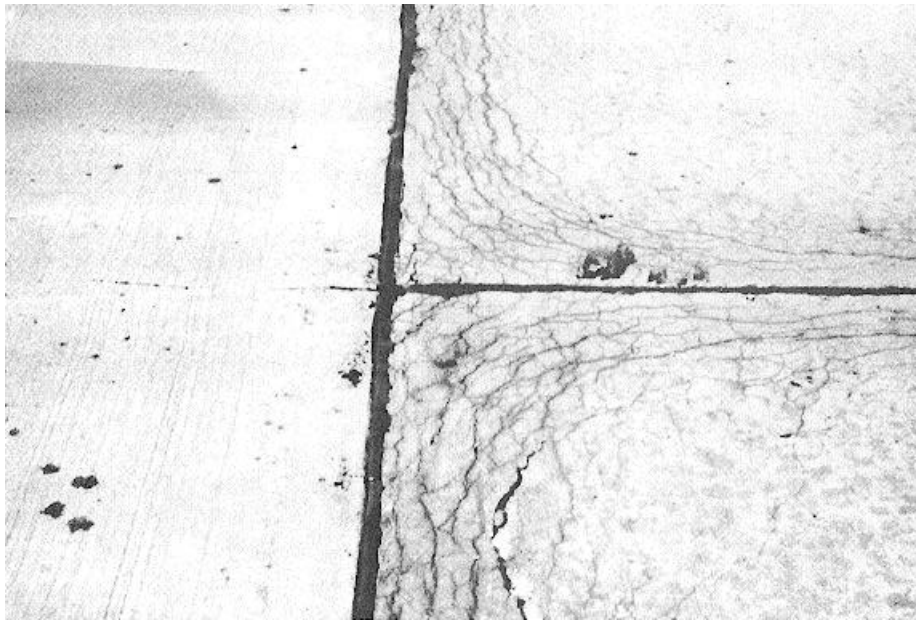
Figure 4-8. D cracking

vehicles which cross it. This distress can also cause increased water infiltration and subsequent damage.

h. Linear cracking (longitudinal, transverse, and diagonal). Linear cracks can be either longitudinal, transverse, or diagonal depending on the orientation of the crack. These cracks usually divide the slab into two or three pieces. Linear cracks (fig 4-12) can result from a number of individual or a combination of causes.

These causes include the following: (1) traffic, (2) lateral contraction or shrinkage of the concrete, (3) lateral warping or curling of the slab, (4) loss of support under the edge of the slab due to nonuniform support, (5) pumping, (6) the presence of expansive subgrade soils under the pavement, (7) and heavy loads. Longitudinal cracking usually occurs in thin slabs 16 feet or more in width without the benefit of a proper longitudinal joint. Transverse cracking occurs at right angles to longitudinal joints. There are several potential
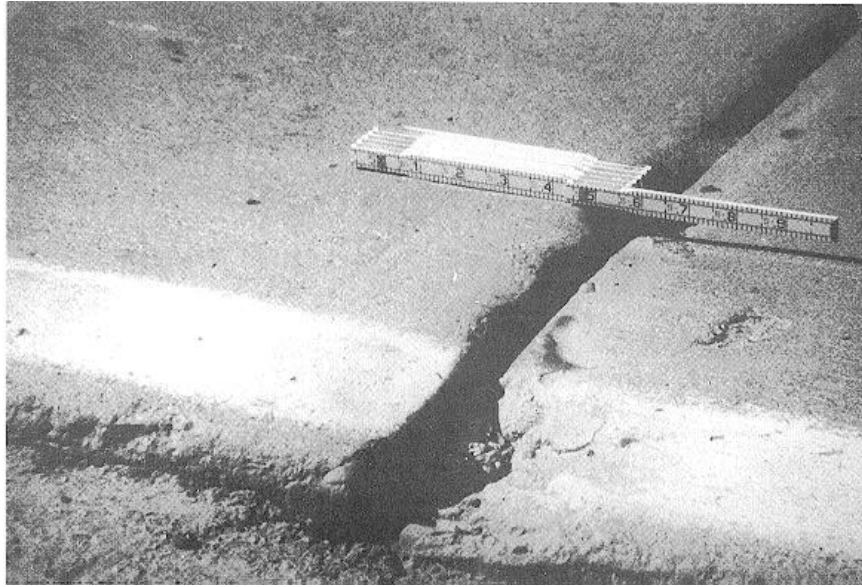
Figure 4-9. Faulting.

Figure 4-10. Joint seal damage, incompressibles in joint.

causes for transverse cracking including: traffic, excessive joint spacing, and improperly cut contraction joints. Overloading and upward curl of slab edges combined with pumping are also possible causes. Diagonal cracking occurs at some angle other than 90 degrees from the longitudinal joint for many of the same reasons provided for transverse cracking.

   i. *Large patch and utility cuts.* These patches include those which have a surface area greater than 5 square feet (fig 4-13).

A large patch is an area where the original pavement has been removed and replaced with a suitable filler material. The patches are usually constructed of concrete, but may also be constructed of asphalt and epoxy. A utility cut is made to allow the installation of underground utilities. The causes of distress of these patches are the same as for any pavement; however, the most frequent problem is poor compaction when filling the cut area. Where a patch was made for a pavement

Figure 4-11. Lane/shoulder dropoff.

Figure 4-12. Liner cracking.

distress, if the distress was not corrected, the patch will fail as the original pavement before it.

j. Small patching. Small patches are those less than 5 square feet in area (fig 4-14). As with a large patch, the area where the original pavement have been removed in small patches is replaced with a filler material.

k. Polished aggregate. Polished aggregate is caused by repeated applications of traffic (fig 4-15).

This distress occurs when the surface aggregate is smooth to the touch and when close examination reveals that the aggregate extending above the concrete is negligible. The traction between the vehicle tires and the pavement is considerably reduced by polished aggregate.

l. Popouts. The Mississippi watershed and especially the Ohio River Valley have problems with soft porous chert in the natural gravel normally obtained from streambeds (fig 4-16). These materials are potentially reactive with alkalis in cement and

4-14

Figure 4-13. Utility cut patch.

Figure 4-14. Small patch.

are susceptible to the phenomenon known as "popouts." The cause of popouts is physical (absorption of water and freezing), chemical (alkali reactivity), or a combination of both. The aggregate will expand and fracture, leaving a hole in the surface of the pavement which may or may not require maintenance.

m. *Pumping* Pavement pumping (fig 4-17) is the forceful ejection of water by deflection of a pavement slab. This usually carries subgrade particles in suspension from beneath the slab and up through cracks, joints, and along pavement edges.

It is caused by an unfavorable combination of free water and subgrade material susceptible to pumping and continuous use by traffic. The slab is forced downward under wheel loads, compressing any free water between the slab and subgrade which forces the water and soil out through cracks and joints. Repetition of this pumping action displaces subgrade soil and results in voids and cavities beneath the

Figure 4-15. Polished aggregate.

Figure 4-16. Popouts.

slab which leave the slab unsupported and subject to cracking. Nonplastic soils such as sands and gravels are practically free from pumping because the soil grains are larger and less susceptible to movement as the water is forced out. Good surface drainage, subdrains, and sealed joints reduce the probability of free water accumulating and contributing to pumping action. During initial construction, provision of a granular base or filter course immediately under the concrete will eliminate or minimize the probability of pumping.

The use of stabilized layers (asphalt, cement) underneath the PCC will also minimize the occurrence of pumping.

n. Punch out. A punch out is a localized area of slab that is broken into pieces (fig 4-18). This distress is usually defined by a crack and a joint or two closely spaced cracks (usually 5 feet wide). It is caused by heavy repeated loads, inadequate slab thickness, loss of foundation support, and/or local

Figure 4-17. Pumping.

Figure 4-18. Punch out.

ized concrete construction deficiency (e.g. honeycombing).

o. Railroad crossing. Railroad crossing distress is characterized by depressions or bumps around the tracks (fig 4-19). This distress is usually a construction defect which causes an uneven surface of low ride quality. When distress is not related to the original construction, it may fit into one of the other categories given in this section.

p. Scaling. Scaling (fig 4-20) is the progressive disintegration and loss of the concrete wearing surface. The major causes of scaling are the physical and chemical reactions of deicing materials in the presence of repetitive freeze-thaw or wet-dry cycles, a weakened surface created by improper mixing, improper curing or overfinishing, and the use of unsuitable aggregates in the mix. Scaling most commonly occurs at locations heavily treated with deicing

Figure 4-19. Railroad crossing.

Figure 4-20. Scaling.

ing chemical such as on hills, curves, bridge decks, or near intersections. Scaling is seldom seen in high quality mixture where severe frost action does not occur. Scaling may be reduced to a minimum by entraining 4 to 7 percent air in the concrete mix.

g. *Crazing*. Crazing (fig 4-21) refers to a network of shallow, fine, or hairline cracks which apparently extend only into the upper surface of the concrete. These cracks tend to intersect at an angle of approximately 120 degrees forming a pattern similar to chicken wire. Crazing usually results from a rapid loss of moisture at the surface through evaporation during

the early curing period causing excessive shrinkage of the surface mortar. The condition can be aggravated by excessive finishing which brings moisture to the surface. Almost all concrete has some surface crazing; however, severe crazing can lead to scaling or other surface deterioration associated with weathering.

r. *Shrinkage cracks*. Cracks often result from stresses caused by contraction or warping of the pavement (fig 4-22). Poor jointing arrangements and/or inadequate curing help generate excessive contraction movement prior to attainment of design strength of new concrete.
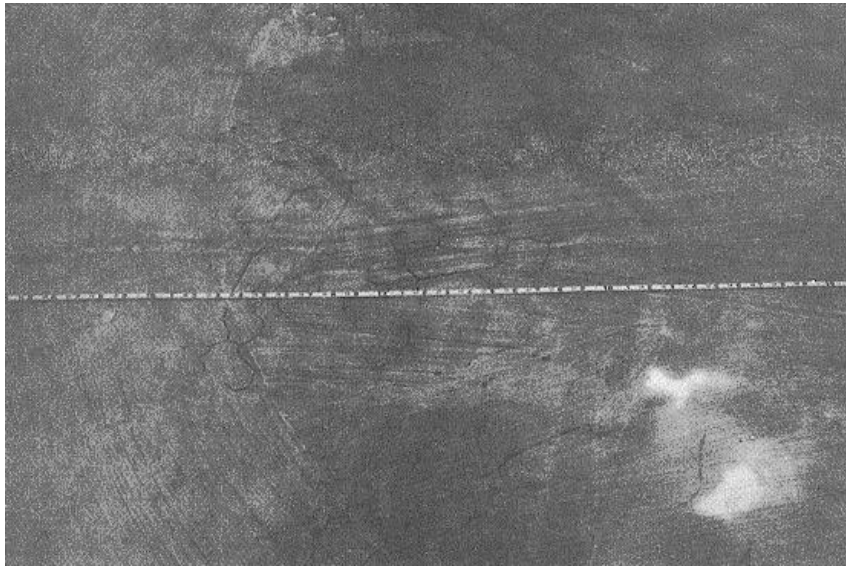
Figure 4-21. Crazing.

Figure 4-22. Shrinkage crack.

s. Corner spalling. Corner spalling (fig 4-23) is characterized by cracking and breaking or chipping of the pavement at the corner of the slab. This breakdown of pavement usually occurs within 2 feet of the corner. The primary cause of spalling is inferior concrete or excessive stress concentration at the joint or crack. The stress concentration may result from several different factors. Major causes include hard pieces of gravel or other debris lodged in a joint or crack, improper forming or sawing of joints, and improper installation of load transfer devices. Inferior concrete at a joint may cause spalling under normal loading as will insufficient pavement thickness. If the thickness is not adequate, excessive deflections under traffic will occur at the corner resulting in spalling or raveling of the concrete. Dowels used as load-transfer devices across expansion joints may cause spalling when not placed perpendicular to the expansion joint and parallel to the surface of the pavement.
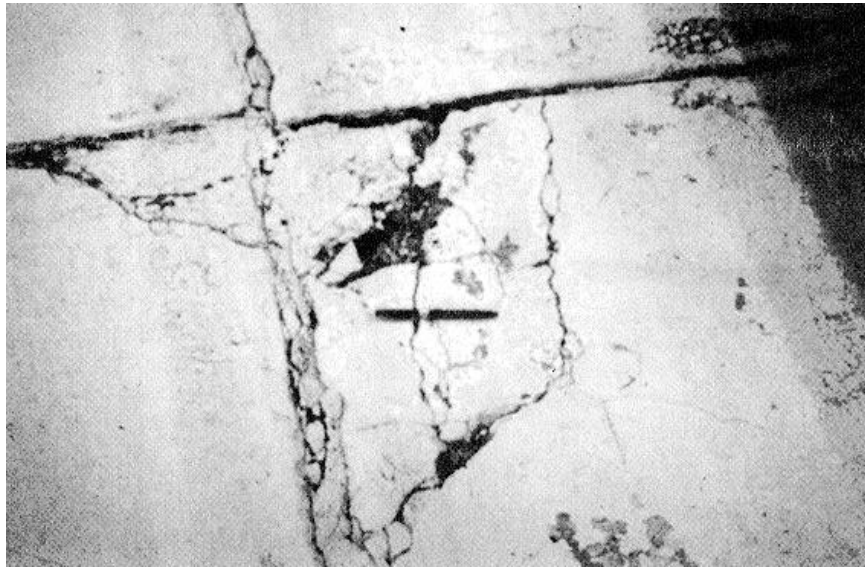
Figure 4-23. Corner spalling.

t. Joint spalling. Joint spalling (fig 4-24) is characterized by cracking and breaking or chipping of the pavement along joints, edges, or cracks. The primary cause of spalling is inferior concrete or excessive stress concentration at the joint or crack. The stress concentration may result from several different factors. Major causes include hard pieces of gravel or other debris lodged in a joint or crack, improper forming or sawing of joints, incorrect type or improperly installed load-transfer devices and rusted "frozen" sliding dowels. Inferior concrete at a joint may cause spalling under normal loading as will insufficient pavement thickness. If the thickness is not adequate, excessive deflections under traffic will occur at joints and cracks resulting in spalling or raveling of the concrete. Dowels used as load-transfer devices across expansion joints may cause spalling when not placed perpendicular to the expansion joint and parallel to the surface of the pavement. Improperly formed joints may also cause spalling.

u. Pavement conducive to hydroplaning. Hydroplaning occurs when a tire loses direct contact with the pavement surface and rides on a film of water. This condition can occur at various speeds depending on the tire pressure, type of tread, and the condition of the pavement surface. When there is a sound concrete surface present, grooving of the concrete may be used to reduce hydroplaning. An AC overlay may be used to restore the pavement surface to an acceptable performance level. When rubber buildup becomes a problem, it can be removed to restore the pavement to an acceptable service level.

4-5. Concrete pavement materials

The basic materials used in concrete pavement include the aggregates and cement binder. These and other materials used in maintenance and repair are given in the following paragraphs.

a. Aggregates. The requirements for aggregates used in PCC are given in paragraph 4-2c(3). The aggregates used for epoxy concretes will be clean, washed, dry gravel or crushed stone, Y8- or V2-inch maximum size, well graded from coarse to fine, and of the same quality used for PCC. It is desirable that the material passing the No. 100 sieve be held to a minimum. The permissible maximum size selected will depend on the intended use of the material. In general, for both epoxy concrete and mortar, the maximum size aggregate will not exceed one-fourth the thickness of the layer being placed or one-fourth the width of the opening being filled.

b. Cement. See paragraph 4-2c(1)(a) for cement requirements. The type of cement selected will depend on local conditions and job requirements. It may be desirable in some cases to get the repaired area back into service with a minimum of delay. In this case, the high-early-strength Type III cements are recommended. Special regulated-set cements, which have the capability of providing very high strength concrete in less than 1/2 hour after mixing, can be used; however, under most conditions the excess cost over Type III cements makes their use prohibitive. Also, the need for such rapid early strength is seldom required in normal installation maintenance operations. Concrete containing high-alumina cement is not recommended due to its in
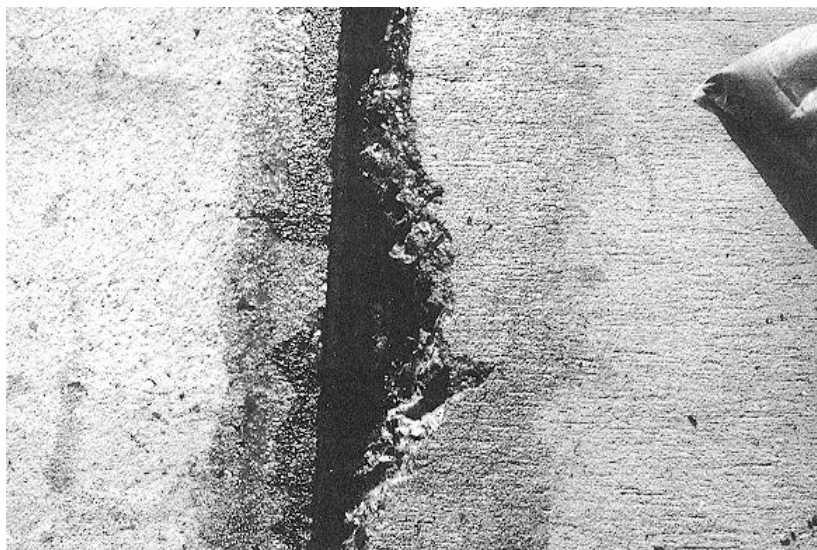
4-20

Figure 4-24. Joint spalling.

stability at temperatures only slightly above normal room temperature when moisture is present. Under these conditions the product exhibits about a 50 percent strength loss. The Type III cements, which are high-early-strength, are recommended for use in repair of bridge decks or other similar areas where it is necessary for traffic to be on the roadway as soon as possible.

c. Sealants. Most of the sealing compounds are of the pourable type; i.e., they are liquids during application and become solid either by cooling or by physical or chemical reactions. Sealants which solidify upon cooling are referred to as "hotpoured." Sealants which solidify by loss of liquefying agent or by chemical reactions are described as "cold applied." Both types are further divided into two groups identified as non-jet-fuel resistant sealers and jet-fuel resistant (JFR) sealers used on airfield pavements where fuel, lubricant, and solvent spillage occur. Cold-applied JFR sealers are also classified as blast resistant.

(1) *Performed sealer.* Another type of joint sealer is the preformed sealer. Preformed sealers have been made for bituminous-impregnated foam rubber (usually polyurethane), cork, and extruded neoprene. The neoprene seal, often referred to as a compression seals have been used in new construction on highway pavements and airfield pavements. An ASTM Specification has been used for purchasing purposes. The use of compression seals in maintenance or repair work has been minimal.

(2) *Hot-applied sealants.* These are sealants which must be heated prior to application.

(a) *Non-fuel resistant.* Rubberized-asphalt sealant (non-fuel resistant) is the most widely used of all hot-applied crack and joint-sealing materials on highways, city streets, and airfields. The sealant is made by dispersing rubber in an asphalt cement of suitable grade. Rubbers have varied from new high-quality reclaimed rubber to low-quality waste, such as buffings from tire-retreading operations. Federal Specifications SS-S-1401C applies to hot-applied non-fuel resistant sealants for concrete and asphalt pavements.

(b) *Fuel resistant.* Sealants consisting of a coal tar base with either rubber of polyvinyl chloride additives have been developed for use on airfield pavements subjected to spillage of fuels, lubricants, and solvents. Locations where spillage occurs are parking aprons and maintenance and refueling areas. Asphalt-base sealants are unsuitable in these areas because the spilled materials are petroleum derivatives and have a solvent action on asphalts, which are also derived from petroleum. Tars, which are only slightly affected by fuel spillage, are produced from coal and have a different chemical makeup than asphalt. Federal Specification SS-S-1614A applied to hot-applied fuel-resistant sealants for concrete pavements.

(3) *Cold-applied sealants.* Sealants which can be applied at ambient temperatures.

(a) *Non-fuel resistant.* Silicone type sealants are most widely used. These sealants are normally applied by extrusion methods and require tooling or smoothing out (not normally self-leveling). Emulsion sealants, although the least expensive, are becoming less popular because of low durability.

(*b*) *Fuel resistant*. Federal specification SS-S-200E applies to two-component, polymer type cold-applied sealants. These sealants are intended for pavements subjected to spillage of fuels and lubricants and to jet blast. These polymer-type sealants are composed of tar and usually polysulfide or polyurethane-based in liquid form. These materials make-up the two components (accelerator or hardener and base or resin) which are combined to form the sealer.

d. Epoxy. Repairs with epoxy materials are costly, and their use which is limited to small areas and application should be by experienced personnel. The repair of spalls on concrete pavement can be accomplished using epoxy resin grouts, mortars, and concretes. Special handling procedures are necessary when using epoxies. There are many types of epoxy resins. The type to be used depends on the application being considered. Under normal conditions, when all precautions are observed, mixed resins may be workable up to 1 hour after mixing. Most epoxy resins are sensitive to water. Water mixed with the epoxy will materially affect the resin reaction and alter the properties of the cured system, if it does not completely prevent the cure. There are systems that are relatively insensitive to water. These are recommended for applications for bonding plastic concrete to hardened concrete. However, even with these systems, the amount of water present must be controlled, and the maximum slump of plastic concrete should be 2 inches or less. A number of specifications have been published for epoxy resins to be used in construction, including ASTM C-881. Epoxy mortars or concretes may be machine- or hand-mixed after the epoxy components have been mixed. Small drum-type mechanical mixers have been used successfully but are difficult to clean properly. Large commercial dough or masonry mortar-type mixers have been widely and successfully used. The epoxy resin material is initially placed in the mixer, the fine aggregate is then added, and then the coarse aggregate is added. This procedure permits proper coating of the fine aggregate particles. Epoxy mortars have short cure times and, except in cold weather, traffic may be permitted on the pavements 4 to 6 hours after repairs. This high strength gain is one of the most favorable features of epoxy repairs, and successful repairs can be made where construction procedures are carefully followed. However, use of epoxy concrete is not normally recommended because of the expense involved and some differences in its expansion properties and those of the adjacent sections. Full details of patching procedures using epoxies are described in TM 5-822-9 and Naval Facilities Engineering Command Instructions 11014.24B.

e. Bituminous material. See chapter 3 for the requirements for bituminous materials.

4-6. Concrete pavement equipment

The equipment listed in this section for each type of repair covers only the specialized equipment normally used for that type of repair. The equipment commonly used in most types of repairs is listed below. Auxiliary and/or alternate equipment not mentioned may be used provided it fulfills the requirements to successfully complete the job.

a. Cleaning equipment. Cleaning equipment includes all the brooms or sweepers necessary for removing excess material. Compressed water and air are often used in cleaning areas to be repaired. For crack and joint repair, it is desirable to have a vacuum pickup sweeper of sufficient size at the worksite to pick up plowed joint materials and debris from cleaning and refacing operations. Such a sweeper will remove old joint sealer from the pavement surface as it is plowed out, thereby preventing these materials from getting back into the joints or being pressed into the pavement surface by other vehicles or equipment used in the work.

b. Miscellaneous hand tools. Miscellaneous hand tools include tools such as picks, shovels, hammers, and other assorted tools.

c. Power saws. A self-propelled power saw with water-cooled diamond or abrasive saw blades (fig 4-25) should be provided for cutting joints to the widths and depths specified or for refacing joints where surface films of oil sealants cannot be readily removed by sandblasting.

d. Pneumatic drill unit. A pneumatic drill rig with assorted drill bits and other necessary equipment is utilized in various ways such as drilling holes for dowel bars and in slab jacking.

e. Water tank truck. A water tank truck is necessary in remote areas (water not directly accessible) where water is required. Although gravity feed may usually be adequate, a pump for water discharge should be included. When cleaning out cracks and joints, an adequate pumping system for high pressure water is advisable (fig 4-26).

f. Air compressor unit. Any air compressor capable of supplying sufficient air for the operation of pneumatic drills, jackhammers, or for blowing out mud and water from cracks and joints is required. A compressor capable of maintaining a line pressure of 90 pounds per square inch at the nozzle is the minimum size suggested for cleaning cracks and joints (fig 4-27). The compressor will be in good operating condition and equipped with traps that will maintain the compressed air system free of oil and water.
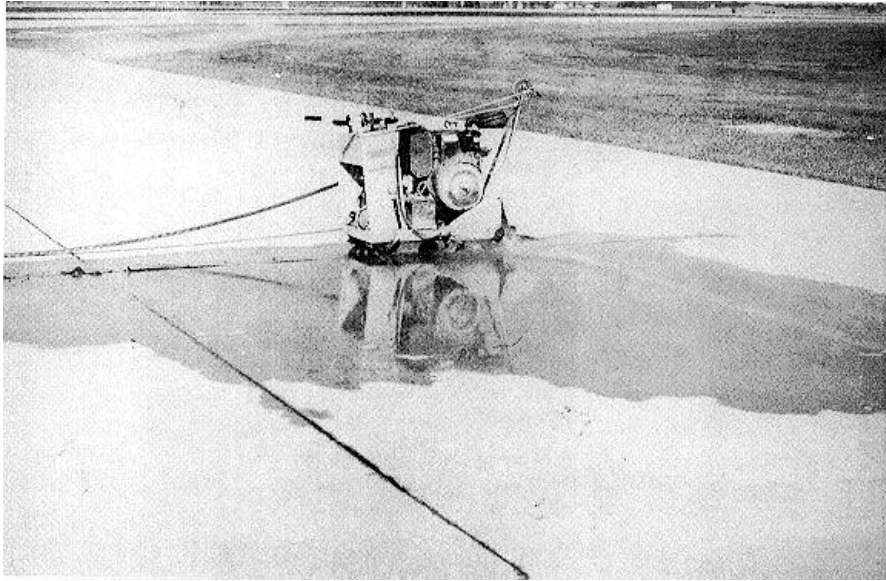
Figure 4-25. Water-cooled power saw.

Figure 4-26. High-pressure water hose.

g. Jackhammers. The jackhammers used shall be of sufficient size and supplied with all necessary bits. Edges of concrete to remain shall be protected and not used as lever points during jack hammering.

h. Trucks. The term trucks covers every vehicle from pickups to dump trucks. The number and type required depend on the work to be accomplished.

i. Patching. The equipment listed is for repairing with PCC. See paragraph 3-5 for equipment required for an asphalt patch.

(1) *Finishing equipment.* Finishing equipment shall include floats, drags, brooms, or anything necessary to get the required finish.

(2) *Front-end loaders.* Front-end loaders are very versatile and are used for moving materials

Figure 4-27. Blowing out dirt from joints.

and placement. The size required will depend upon its intended use.

(3) *Grad-all or suitable pavement remover.* This equipment is used to remove broken slabs and/or large sections of pavement to be repaired.

j. Crack and joint sealing. The following paragraphs detail the equipment used to seal cracks and joints.

(1) *Joint plows.* Dummy groove joints, expansion joints, and construction joints can be cleaned with a specially made tool attached to a farm tractor (fig 4-28). The cutting tool will be equipped with a properly adjusted spring or hydraulic holding device. Contact with any wedged foreign object, irregular joint wall surface, nonalignment, or joint at intersections will release pressure on the cutting tool prior to causing concrete damage along the joint edges. V-shaped tools or rotary impact routing devices will not be used as damage to the sides of the joint may occur.

(2) *Powered routers.* Cracks and joints containing material to be removed are normally plowed first to remove the bulk of the material. The remaining material not removed by plowing may be removed by waterblast, sandblast, or saw cutting. The router should be designed for removing residue of material from the joints and for refacing the joints to provide a clean, vertical concrete face. The power cutter should be a self-powered machine operating a vertical spindle revolving cutting tool (fig 4-29). The vertical impact router (fig 4-30) has been used; however, it will tend to leave rounded or spalled joint edges. A power-driven rotary routing tool with a V-shaped end (similar to a high-speed drill) works best for cleaning random cracks.

(3) *Power brush.* A power-driven wire brush may be used after plowing when necessary to clean joints and cracks. The brushing will avoid further widening or injury to sidewalls. However, it can only be used if the new sealant is compatible with the old sealant. Two precautions on the use of wire brushes are that they spread and burn-in any residual sealant, and they lay down their own metallic luster on the concrete. Sand blasting is usually required after using a brush. Wire brushes are considered a detriment except as stated above.

(4) *Sand blasting.* Sand blasting equipment is the most reliable method for final removal of joint materials and for removal of curing membrane and debris from sawed or formed joints in concrete replacement areas. The nozzles used for sand blasting must have a diameter smaller than the width of the joint and be equipped with an adjustable guide that will hold the nozzles aligned with the joint about 1 inch above the pavement surface (fig 4-31). The height, size of nozzle, and angle of inclination will be adjusted to secure the results desired. Adjacent aircraft, vehicles, and people must be protected.

(5) *Water blasting.* Water blasting with high-pressure water jet equipment should include trailer-mounted water tank, pumps, high-pressure hose, wands with safety release cutoff controls, nozzles, and auxiliary water resupply equipment. The water tank and auxiliary resupply equipment should be of sufficient capacity to permit continuous operations. Pumps, hoses, wands, and nozzles should be of such design, and operate at such water pressure and rate of discharge to clean the bottom
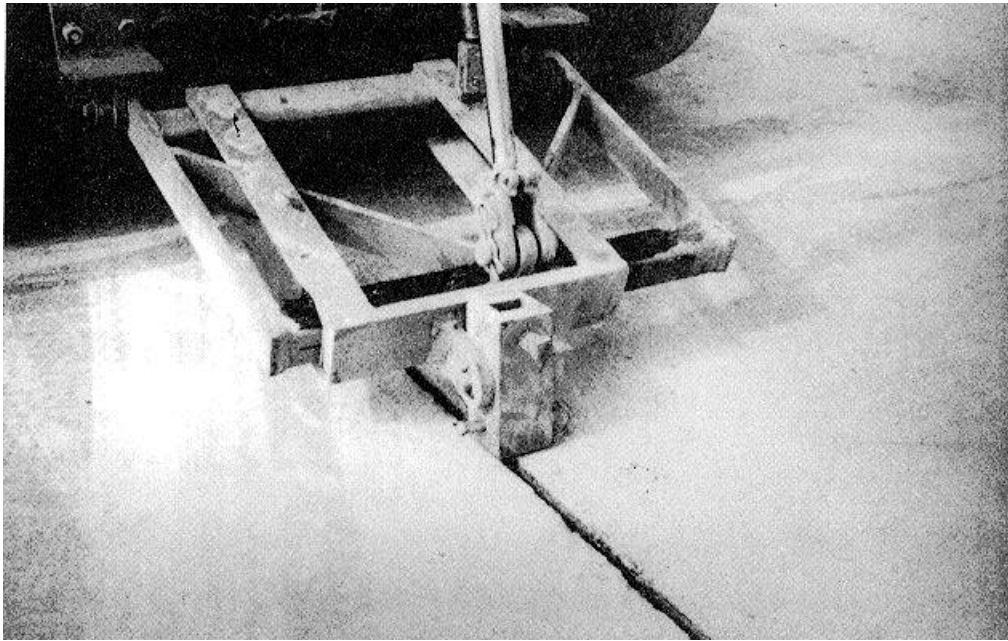
Figure 4-28. Joint plow.

Figure 4-29. Vertical router spindle.

and both walls of the joint. They should also be able to clean the pavement surface on both sides of the joint for a width of at least ½ inch. A pressure gage should be mounted at the pump which will show at all times the pressure in pounds per square inch at which the equipment is operating. Waterblasting may not be suitable where base course material cannot sustain localized saturation or where displacement of the base course material would occur.

(6) *Compressed air*. Compressed air should be used last, after any or all of the previously cleaning methods and just before sealant application. The requirements for compressed air equipment are similar to those of waterblasting.
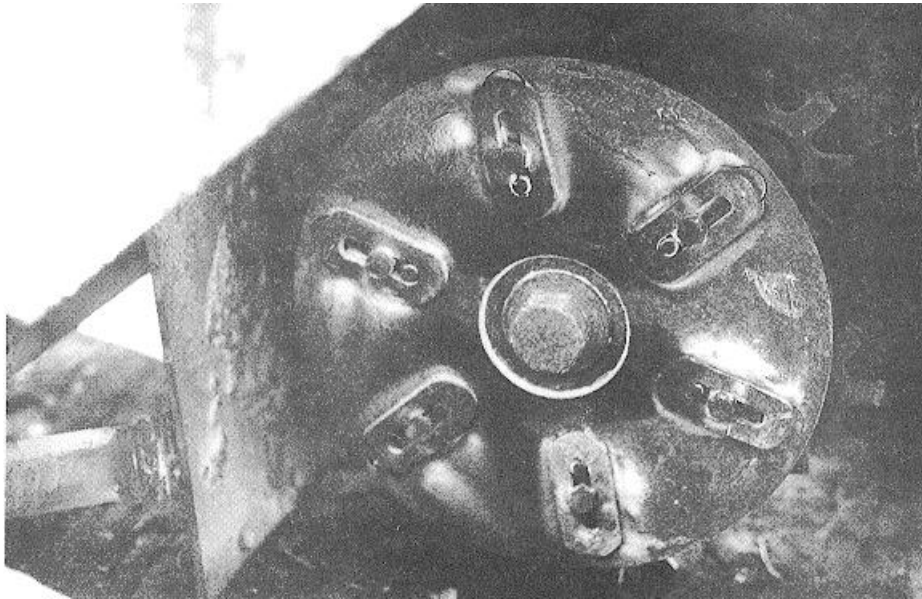
Figure 4-30. Vertical impact routing device.

Figure 4-31. Sand blasting joints.

(7) *Portable melting units*. These portable melting units are usually double-boiler-type melters and use an indirect heating method. They use a heat-transfer oil between the inner kettle and outer jacket; the oil is the medium which transfers the heat from the flame to the sealer material. The unit must have a method of agitating and recirculating the material and be able to obtain temperatures ranging from 200 to 300 degrees F.

(8) *Pouring pots*. Pouring pots are hand held pots which can be used to pour heated sealers into cracks (fig 4-32). This method should not be utilized except on small cracks less than 1/8 inch wide or in areas inaccessible to other types of equipment.

(9) *Joint material applicators*. One type of applicator uses a pressure base attached directly to a
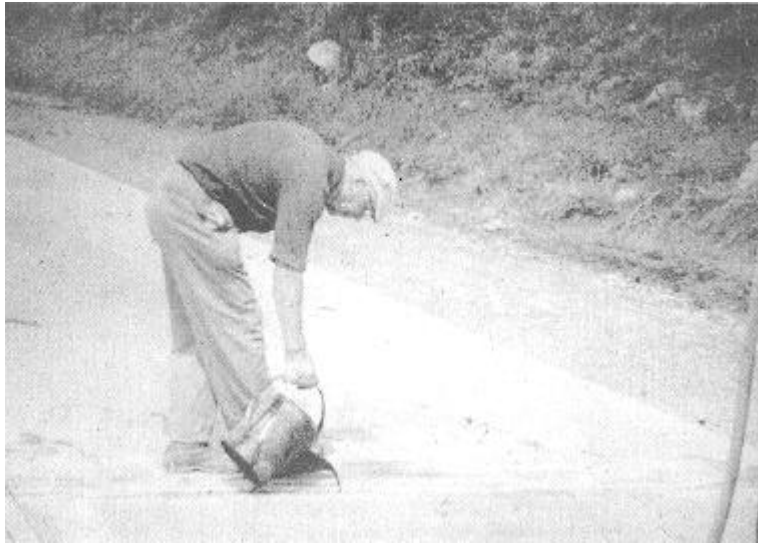
Figure 4-32. Applying crack sealer with a pouring pot.

pump unit on the melting kettle in a manner which permits pumping the sealer through the base to a suitable applicator (fig 4-33). Another method is where the sealer is forced by gravity into the joints from the applicator. In the last method a self contained insulated pressure unit is used to apply the sealant.

k. Slab jacking. The following paragraphs describe the equipment used in slabjacking

(1) *Concrete or pugmill-type mortar* mixer. The mixer unit must be capable of producing a quantity of mix to be compatible with the jacking unit used.

(2) *Hydraulic jacking unit.* A hydraulic jacking unit of the positive-displacement type capable of instantaneous control of grout pressure is required.

(3) *Concrete buggy.* A concrete buggy is required to transport the grout from the mixer to the jacking unit.

(4) *Plugs.* Hardwood plugs with a slight taper are required for each hole drilled.

1. *Bituminous undersealing.* The asphalt tank will be equipped with a method of circulating the asphalt and utilizing indirect heat for the asphalt. The pump attached to the heating tank will be a bituminous pressure type equipped with flexible metal hose and a tapered nozzle which can be inserted into the drilled holes for more efficient penetration. A nozzle equipped with three-way valve and double hose permitting circulation of hot asphalt is preferable. Hardwood plugs with a slight taper are required for each hole drilled.

4-7.   Methods of concrete maintenance and repair
The objective of maintenance is to keep the concrete pavement in a satisfactory condition. Prompt and adequate maintenance greatly extends the useful life of a pavement. Maximum benefits will be obtained when seasonal maintenance operations such as sealing cracks and joints and patching are performed at the proper time and according to accepted practices.

a. Concrete patches. Concrete is most desirable for patching deterioration in rigid pavements because it preserves uniformity of appearance and provides a strong durable repair. Concrete patches consist of partial-depth patches and full-depth patches.

(1) *Partial-depth* patches.   Partial-depth patches involve removing the concrete from the surface down to sound concrete. For this type of patch, the edges will be squared and the sides cut vertical using a concrete saw or air hammer. Where there is distress at a joint due to spalling or any other cause where a partial-depth patch is required, the following procedure for removal and repair is recommended. Using a power saw a vertical cut should be made a minimum of 12 inches deep and approximately 2 inches back of the distressed area for the entire length of the damaged section. Cuts should be made at corners and along the edges of the patch so that a square or rectangular patch with vertical sides is obtained (fig 4-34). After making cuts with
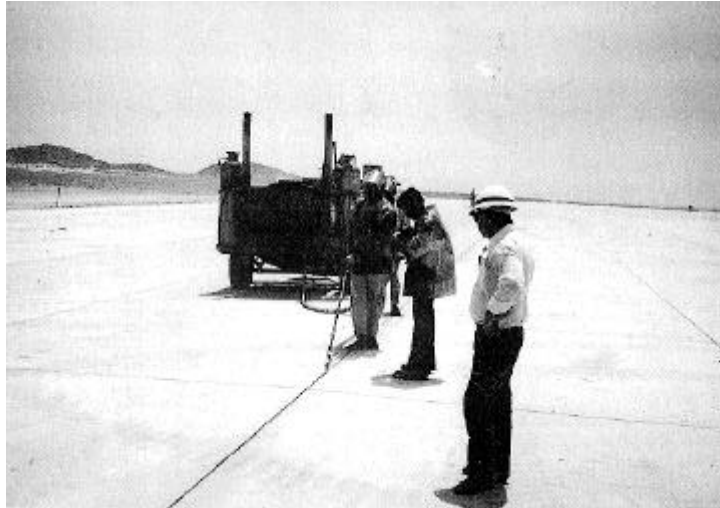
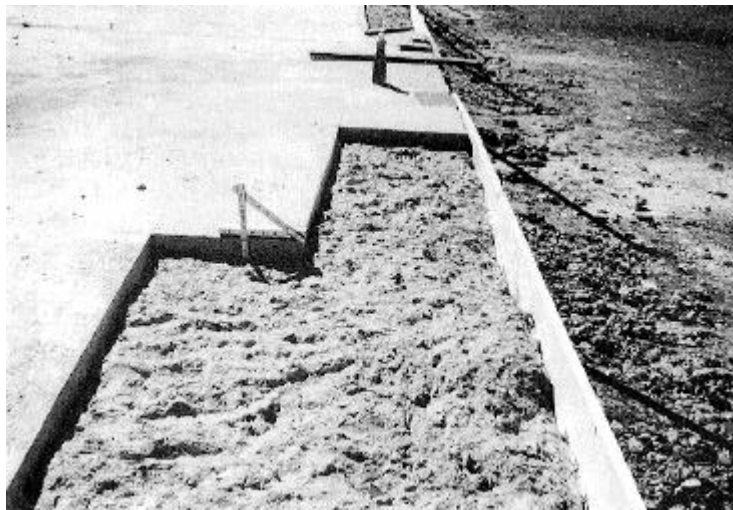*Figure 4-33. Applying joint material.*

Figure 4-34. Prepared partial-depth patch.

the power saw, the unsound concrete between the saw cut and the joint to be repaired should be broken out with pneumatic drills and hammers. Compressed air should be used to blow off the residual dust from sawing, chipping, or drilling operations. The area should be thoroughly pressure rinsed after all the unsound concrete has been removed and the fines blown off. Thoroughly scrub any oil-soaked

areas with a suitable detergent. The use of muriatic acid for cleaning the surface, especially for epoxy repairs, is not recommended. This process is sometimes used to assure that sound, clean concrete is exposed over the entire area to be repaired. The muriatic acid etching process can normally be eliminated by using mechanical abrasion to expose sound, clean concrete. The surface should be treated

with a bonding grout mixture to ensure a tight contact between the existing pavement and the freshly repaired concrete. The grout or bonding mortar will be composed of one part Portland cement to one part fine sand and will not contain more than 5 gallons of water per sack of cement. The mortar will be mixed to a thick, creamy mixture in an approved mechanized mixer. The bonding grout should be applied immediately preceding the concrete patch mixture and spread over the entire surface with a stiff broom or brush to a depth of 1/16 inch. Place a thin strip of wood, asphalt impregnated fiberboard or metal coated with bond-breaking material or lined with plastic in the joint groove, and tamp the new mix onto the old surface and against the form. Care will be taken in placing the filler board or joint cap so that it is aligned with the existing joint. One should ensure that the mixture used for joint repairs is an air-entrained concrete of high-quality materials. The proportions of cement and aggregate to be used in the mix can be determined by batch design tests. The maximum size of the coarse aggregates will be governed by the depth of the patches to be placed. The coarse aggregate will not contain particles larger than one-third the depth of the patch. Generally, the mixture will have a sand to aggregate ratio between 0.40 and 0.50 by weight. The mix will be designed to produce a "dry" no-slump concrete which will require tamping or vibrating to place in the patch. The patching material should be mixed in an approved rotary drum or pugmill-type mixer. For small quantities of patch

mixture, hand-mixing methods may be employed. Mixing must produce a homogeneous, nonsegregated mixture. After the bonding grout has been brushed into the surface of the area to be repaired, the concrete patching mixture should be placed within 10 minutes and before grout has begun to dry. Tamping or vibrating the mixture to ensure consolidation and positive bonding with the existing concrete is required. Mixture not placed within 30 minutes should be discarded, and a new batch must be prepared. When the finishing and edging have been completed, the patch will be broom finished to a texture matching the adjacent areas. When concrete has attained its initial set, the filler board will be removed and the joint cleaned with a hook or similar device. This procedure is necessary to ensure that no damage to the patched area will result from excessive stresses during expansion of the concrete. All patched areas will be cured by a covering of wet burlap or curing membrane for a minimum 3-day period after which the open joints will be filled with joint material prior to permitting use by traffic. A complete joint repair is shown in figure 4-35.

(2) *Full-depth patches.* For full-depth patches, the concrete will be sawed out approximately 6 inches outside of each end of the broken section and removed down to the base material. When patching near joints or on edges (fig 4-36), the concrete will be placed about 2 inches thicker than the adjacent pavement, and the patching material will extend about 2 inches under the in-place concrete. If the
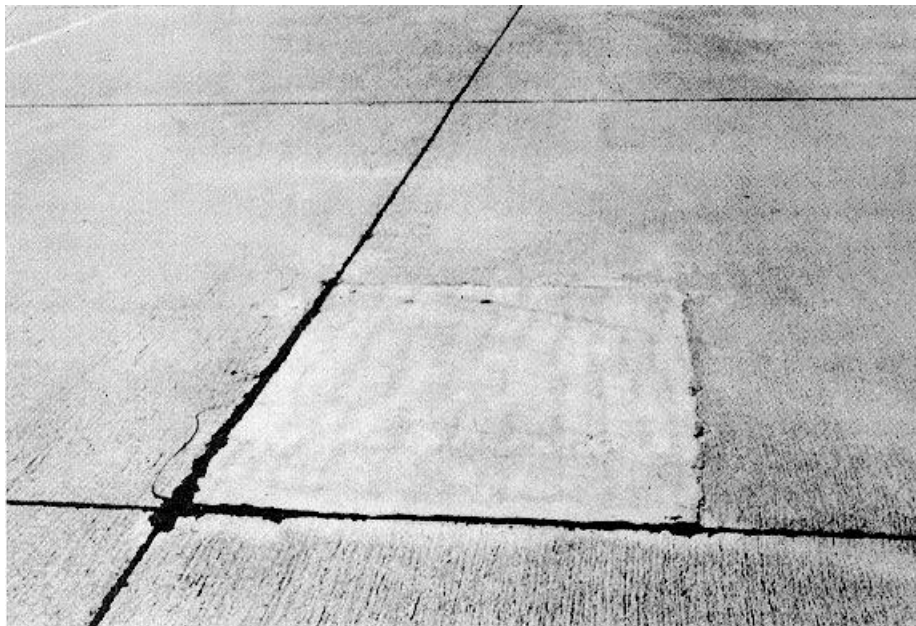

Figure 4-35. Completed patch.

distress is at a working joint, the patch must not impede movement of the joint. Bond-breaking systems such as polyethylene sheeting or grease should be used. If distress is located at transverse joints, a plastic or fiber joint material should be placed at the joint prior to filling the cavity where required dowel bars and other reinforcement will be placed as required (fig 4-37). The thickness of concrete at all patches will be as thick as the existing slab. For utility trenches, new patches will be a minimum of 4 inches thick but not less than 2 inches thicker than the existing slab.

(3) *Concrete mix.* Ready-mixed concrete should be used if it is satisfactory and can be obtained economically. For repairing runways or taxiways, it is desirable to use a mixture providing high-early

strength, thereby permitting the earliest possible use. For small patching jobs, concrete in small ¼- to ½-bag mixes is acceptable. Material proportions for small batches are indicated in paragraph 4-2c(6). To obtain more uniform mixes, all batching will be done by weight. Batches will be mixed for a minimum period of 1 minute to secure a homogeneous mix. Only high-quality materials will be used for concrete repairs. Materials will be properly proportioned and a minimum amount of water used for mixing. Air-entrained concrete will be used for all patching and repairs.

(4) *Placing concrete.* Prior to the placement of new concrete patches, edges of adjacent slabs and the cavity for shallow patches will be free from dust, loose concrete, dirt, or other foreign materials
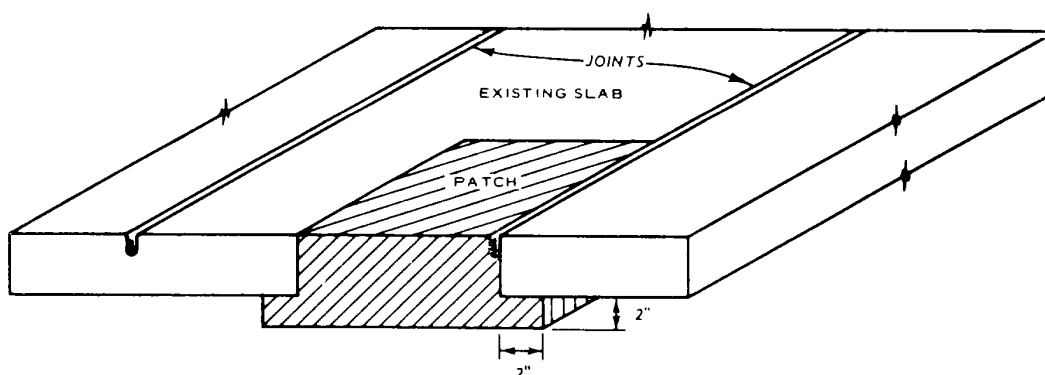

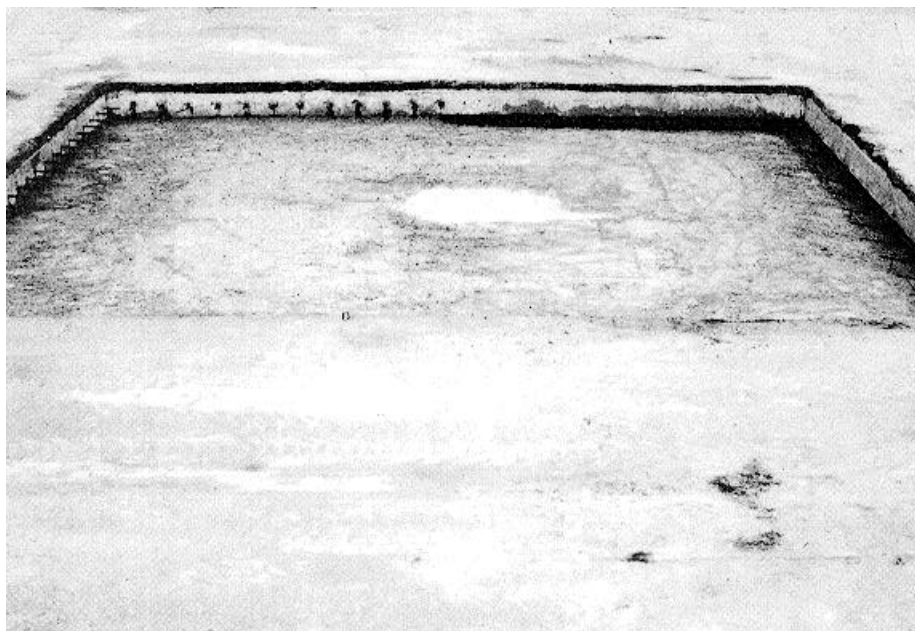*Figure 4-36. Patching near joint or pavement edge.*

Figure 4-37. Full-depth patch with dowel bars at edges.

(fig 4-38). The cavity for the shallow patch must be primed with cement grout or epoxy grout, as appropriate. Vertical surfaces for deep patches must be moist with water, or the internal face should be primed with plain or epoxy grout. The subgrade or base material will be moistened to prevent the absorption of water from fresh concrete. If steel forms are used, the forms will be greased; new wood forms will be dampened with water. The joints will be set in place prior to placement of the concrete. In reinforced pavement construction, joint techniques are used to tie the new concrete to the old reinforced material (fig 4-39) when constructing a patch. The replacement joint will be doweled and built to joint specifications. This may be an expansion joint with the traditional filler for expansion space, or it may be a contraction joint if expansion space already has been provided at some nearby location. The areas to be patched will be filled with concrete and tamped or vibrated and screeded off at a slightly higher level than the adjacent finished surface (fig 4-40). Mechanical vibrating equipment consolidates the

Figure 4-38. Cleaning patch area with compressed air.

Figure 4-39. Placing reinforcement and dowels in area to be repaired.

4-31

freshly placed concrete quickly and efficiently. If drier mixes are used, thorough tamping is absolutely essential to ensure consolidation, a minimum of voids, and elimination of honeycombing in the concrete. Tamping along the edges forces concrete firmly against the existing slab and helps to prevent separation caused by shrinkage during the curing period.

(5) *Finshing.* Surface texture of new patches. will be approximate to that of existing pavement.

The concrete will be floated and the surface finished using canvas, rubber belting, burlap drags, or brooms (fig 4-41). New continuous joints, if necessary, ill be constructed in the patch to match existing joints.

(6) *Curing.* Immediately after completion of finishing operations, the new surface will be covered and kept damp for a period of several days, or membrane curing compound will be applied to prevent loss of moisture from the new concrete. A cur-

Figure 4-40. Placing concrete in patch area.

Figure 4-41. Finishing surface of concrete patch.-

ing technique will be applied as soon as the new patch surface is hard enough to resist marking. The area will be surrounded by a barricade and traffic barred from the area until concrete has attained sufficient strength to carry loads (approximately 3 days). Military Construction Guide Specification 02515 and AFM 91-23 provide guidance regarding methods for curing concrete.

b. Bituminous patching. See chapter 3 for procedures pertinent to the use of bituminous material. Broken concrete areas can be patched with bituminous mixes when conditions require repair. In some cases, the bituminous patch can be left in place if there is no objection to discoloration of the surface. Normal traffic may be permitted on bituminous patches immediately after completion of the patch. Hot bituminous patches allow traffic on the pavement immediately after completion; however, the life of these patches is relatively short in comparison to concrete patches.

c. Slab replacement. When normal maintenance procedures can no longer adequately prevent or correct effects of ordinary pavement wear and use, repairs may become necessary to restore damaged areas to their original condition. Replacement is generally necessary when slabs have been broken or have deteriorated to such extent that safe support of the required loads is no longer possible. Repair work also may include pavement resurfacing.

(1) *Replacement of broken areas,* blowups, and utility cuts. Badly cracked, broken, or deteriorated pavement areas will be removed entirely and replaced with new concrete. Manual concrete removal will be considered only when mechanical methods are not practical or equipment is not available. Manual removal will be restricted to small areas. Heavy sledges may be used for breaking pavements, if necessary, but adequate precautions will be observed at all times. The use of mechanical equipment will greatly accelerate these operations and appreciably reduce the cost of repair. Such equipment includes portable air compressors, pneumatic pavement breakers complete with chisels and bits, and various small tools. Boundaries of the areas to be repaired will be outlined and cut using a concrete saw, if available, to a depth of 2 inches to ensure clean vertical edges for repairs. When cutting slabs for the purpose of making utility repairs or installations, the concrete will be cut back to about 9 inches beyond the limits of the trench, thereby providing adequate subgrade support of the new patched areas. Backfill trenches are required in original construction with materials having similar physical properties as the adjacent undisturbed materials and thoroughly compact to densities.

(2) *Subgrade.* Pavement breakage is usually caused by undesirable conditions affecting the base and subgrade, e.g., frost, seepage, subgrade settlement, or overloading. Unstable subgrade materials will be removed to a minimum depth of 12 inches and replaced with selected nonplastic granular materials. The subgrade under replacement or repaired areas will be stabilized and compacted at optimum moisture content prior to replacement of the patch. Poor drainage will be corrected by the installation of adequate drains for the interception and removal of excess water. Utility trenches should be shaped in the subgrade so that adjacent materials are not disturbed. All materials will be compacted thoroughly in layers at optimum moisture content, thereby preventing future settlement. This is especially true with utility cut repairs.

d. Crack and joint sealing. Crack and joint sealing is used to prevent damage to the pavement structure from water passing through the pavement and into the underlying layers. Sealing will prevent the accumulation of foreign matter in cracks and joints. Sealing will also protect expansion joint materials which tend to deteriorate and become inert if not protected.

(1) *General.* To make the concrete slabs crack in neat straight lines, which simplifies maintenance, joints are placed at predetermined intervals. Contraction joints are formed either with preformed inserts or sawed to a minimum depth of ¼ of its thickness, normally within 8 to 24 hours after concrete placement. Full-depth joints are junctions placed between slabs to permit expansion, to control cracking, or to meet construction requirements. Joints formed by inserts or sawing are used to induce cracking along with resulting weakened plane. Depending on the construction and function, joints can be classified as expansion, contraction, or construction joints. Another type of joint, the longitudinal construction or shoulder joint, is found between the concrete slab and the shoulder of the road. Expansion and contraction joints which are not functioning properly due to accumulation of foreign matter in the joint frequently cause spalling of the concrete at the joint and can be the cause of pavement blowups. A walking inspection of the pavement by competent personnel and close observation of the condition of the joints reveal the need for resealing. The person making such an inspection determines whether the existing joint seals are bonded to the adjacent concrete; whether the material has become oxidized and brittle; or whether, due to expansion and construction, fine sands have formed a thin separation between the joint material and the sides of the joint. Cracks in the pavement should be sealed only if the crack is working and extends the full depth of the pavement. Much effort

and material are wasted, and unsightly conditions are created by attempts to seal narrow, tight, cracks. Procedures for determining sealing requirements and proper installation are outlined in TM 5-822-11/AFM 88-6, chapter 7.

(2) *Preparation of the joints and cracks.* Joints and cracks must be thoroughly cleaned of old jointsealing materials, dirt, oil, and other foreign material to a depth of not less than 1 inch. Cracks that are working, spalled, or are at least V4 inch in width, will be cleaned by brooming and blowing with compressed air. All cracks, whether previously sealed or not, will be properly routed or sawed to a minimum depth of Y4 inch and to the minimum width necessary to ensure clean surfaces on each side. This is difficult to obtain without excess injury and widening, unless the proper saws and vertical spindle routers are used. All joints and cracks will be thoroughly dry before application of sealing materials. Additional detailed information is available in AFR 88-35; AFM 91-23; TM 5-822-11/AFM 88-6, chapter 7. Methods of sealing joints and cracks vary according to size of areas involved. Use mechanical equipment to the maximum extent on board areas of pavement and use hand equipment only where necessary.

e. Undersealing. Undersealing is the term applied to bituminous material injected under pavements to fill and prevent minor voids caused by pumping action.

(1) *Undersealing materials.* Bituminous undersealing is mainly used to fill voids about V2 inch in depth. The use of asphalt to fill voids greater than 1 inch in depth or to raise slabs is not recommended. Only asphalt especially prepared for undersealing will be used. Recommended asphalt will have a penetration range of 15 to 30, a softening point range of 180 to 200 degrees F, be of suitable consistency for pumping when heated to a temperature of 400 to 500 degrees F, and be resistant to displacement in the pavement when cooled.

(2) *Procedure.* The method of placing bituminous undersealing is practically the same as that used for slabjacking using grout. The asphalt cement will be heated in the bituminous distributor tank to a temperature of between 400 and 500 degrees F. All water will be removed from beneath the slab with compressed air prior to pumping of the hot asphalt. The tapered nozzle on the asphalt hose will be driven tightly into the drilled hole and asphalt injected under pressure. The nozzle will be allowed to remain in a hole for approximately 1 minute after pumping ceases and pressure is reduced and then will be removed and the hole plugged. Pumping pressures will range from 20 to 40 pounds per square inch under normal conditions.

During pumping, water will be sprayed on the pavement adjacent to the drilled holes to prevent discoloration of the surface. Water saturated with hydrated lime is considered most suitable since spilled asphalt will then chill quickly and can be easily removed. Asphalt seeping up through cracks or joints can be quickly chilled and hardened by application of cold water.

f. Slabjacking. Slabjacking is used to raise the elevation of a slab or a portion of a slab. Slab elevation differentials create dips which are hazardous to traffic. This may cause breakage of slabs by impact loading of traffic.

(1) *Purpose of slabjacking.* The term "slabjacking" describes an operation known for many years as "mudjacking." Mud or soil-water mixtures are no longer used to jack pavements; finely ground limestone or sand and Portland cement mixtures are presently used. The purposes of slabjacking are simple. As grout is pumped under pressure through a hole cored in the pavement into the void under the pavement, it creates an upward pressure on the bottom of the slab in the area around the void. The upward pressure lessens as the distance from the grout hole increases. This is due to the viscosity of the grout and the skin friction created by the flow of the grout. Thus, it is possible to raise one corner of a slab without raising the entire slab. Joints in concrete pavements are pumping or expelling water and soil fines out of the joints or at edge of the pavement as traffic passes. A minor change of elevation in the existing pavement is necessary to realign surface of slabs to improve drainage characteristics. Slabjacking will not increase the design load carrying capacity of a concrete pavement and should never be considered with pavement strengthening projects except when there is a requirement to correct conditions listed above prior to placement of a strengthening overlay. Slabjacking is futile when the pavement is already badly cracked. AFM 91-23 provides guidance on slabjacking procedures.

(2) *Grout mixture.* A variety of grout mixes have been used successfully for slabjacking. They generally consist of three to seven parts fine sand or finely ground limestone and one part Portland cement with water added to produce the desired consistency. In areas where ground limestone is not readily available, hydrated lime has been used. A grout mixture of 20 percent cement and well-graded clean sand (30 percent or more fines passing the No. 200 sieve) can be easily pumped and will develop adequate strength. No pressure grouting operations will be performed when the ambient temperature is below 40 degrees F. Addition of calcium chloride (approximately 5 percent at 40-55 degrees F ambient

temperature and percentages ranging down to 1 percent at 99 degrees F and above) has been used successfully in grouting operations. Wetting agents and additives that increase flowability may also be used in the mix. A wetting agent lubricates the grout and permits runs up to 6 feet. Generally, a mix of stiff consistency is used for raising pavement slabs; a more fluid mix is used for filling voids. The proper consistency to be used for any given condition is best determined by experience.

(3) *Location of injection holes.* Slabjacking is an art, not a science, and should be carried out by competent, experienced crews. This is particularly true concerning the location of holes for injecting the grout. The operator must learn to space the holes according to the particular job and manner in which the slab must be raised or tilted. As a general rule, holes will not be placed closer than 18 inches from edges or joints. They will be located on not more than 6-foot centers so that not more than 25 to 30 square feet of slab is raised by pumping any one hole. Additional holes may be required if the slabs are cracked. The proper location of holes varies according to the defect to be corrected (fig 4-42). For pumping joints where faulting has not occurred, a minimum of two holes can be used. For a pumping joint with one corner of the slab faulted, the hole at the low corner should be set back to avoid raising the adjacent slab. Holes 1-14 to 1 inch in diameter will be drilled by a core drill or a pneumatic drill.

(4) *Slabjacking procedures.* Before work is started, some method of controlling the amount the slab is to be raised and the finished elevation of the pavement will be determined. For correcting faulted slabs, a straight edge may be used. For short dips up to 50 feet, a tight chalk line is adequate, providing the joints used are in a true plane with the adjacent pavement in each direction. For dips in excess of 50 feet, a precise level and rod will be used to check the profile well beyond the dip. This will avoid leaving a "bump" in the pavement. Leveling slabs at faulted joints or cracks is best performed during cool weather when the pavement is contracted and joints are open. For correcting a dip or

sag in the pavement, jacking will begin at the low point of the sag and progress longitudinally, staggering the holes transversely until the slab has been raised to desired elevation. All holes will then be pumped to make certain no voids remain under the slab. Slabs will not be raised more than 1/4 inch while pumping into any one hole at any one time. The entire slab and adjacent slabs will always be kept in the same plane within 1/4 inch to avoid cracking. When using two jacks, it is not desirable to work adjacent holes simultaneously. This may cause a line of stress that could crack the slab. In all slabjacking operations, the slab will be raised slowly with a uniform pressure. Care will be taken to ensure that an undesirable buildup of grout or "pyramiding" does not occur around the hole through which the grout is being pumped, or the slab may crack. When the primary purpose of the operation is to fill voids, pumping in one hole will continue until the grout begins to flow from adjacent holes. Adjacent holes may be temporarily sealed with wooden plugs which can be readily removed following the setting of the grout. When the nozzle is removed following the completion of slabjacking operations, all holes will be cleared and filled with a stiff 1- to 3-inch slump mortar mixture which will be tamped into place and floated to a smooth finish. Generally, a slabjacking crew consists of 6 to 10 men, a foreman, and at least one flagman.

g. Slab grinding. This method can be used where there is faulting between slabs or cracks within a slab. The procedure used is to grind the high side of the pavement down to the level of the other side. A more permanent solution is to use slabjacking or if the distress is severe, slab replacement.

h. Grooving. Grooving is used to improve the skid resistance of concrete pavements. Grooving is the construction of a series of small grooves or cuts in the pavement surface, usually 1/4 by 1/4 inch and spaced 1 1/4 inches apart. Grooving should be done in the transverse direction for airfields. Longitudinal grooves are used on roadways.
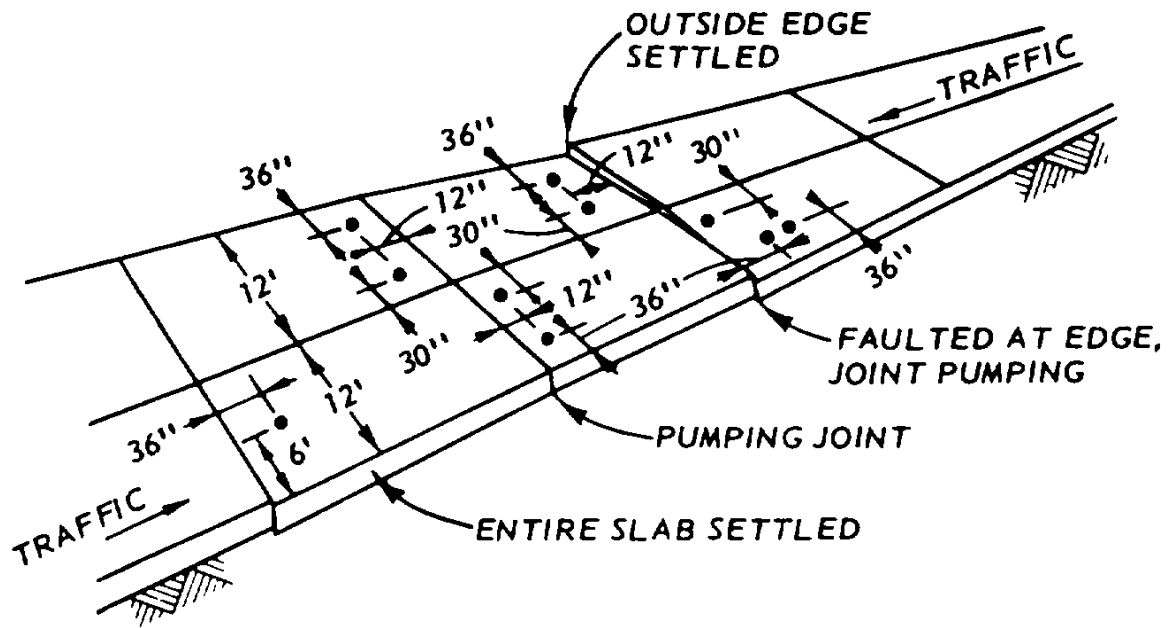
Figure 4-42. Proper location of holes depending on defect to be corrected.